Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: July 28, 1971

to: Distribution

B71 07042

from: C. Bendersky

subject: AF/OOS Propulsion Reviews, Los Angeles, California, June 23-24, 1971 - Case 237

ABSTRACT

The Air Force Orbit-to-Orbit Shuttle is an 80,000 lb gross weight propulsion module similar to the NASA Space Tug. It is capable of delivering 10,000 lb to, or returning 3500 lb from synchronous orbit. Recent studies have been concerned with the effect of propulsion system design on stage performance.

Parametric data concerning weight and performance have been derived for a number of different types of hydrogen-oxygen rocket engines at several thrust levels between 8000 lb and 50,000 lb. Payload performance of stages using these data were compared and it was found that staged combustion type engines were the best and that the optimum thrust should total 20,000 lbs.

(NASA-CR-121323) AF/OOS PROPULSION REVIEWS, LOS ANGELES, CALIFORNIA, JUNE 23-24, 1971 (Bellcomm, Inc.) 17 p

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

A previous memorandum* described the Air Force sponsored studies on H_2/O_2 Orbit-to-Orbit Shuttles (OOS), a propulsion module in many ways similar to the NASA tug concept. It was reported that the Air Force Space and Missile System Organization (SAMSO) has both the North American Rockwell Space Division (NAR/SD) and the McDonnell Douglas Astronautics Company-West (MDAC-W) under contract to perform vehicle systems studies. In direct support of these studies the AF Rocket Propulsion Laboratory (RPL) has the Aerojet Liquid Rocket Company (ALRC), Pratt and Whitney Aircraft Company (P&W) and the Rocketdyne Division of North American Rockwell (RKD) under contract to define the characteristics of the high performance H_2/O_2 main propulsion for the OOS.

Propulsion oriented reviews of the vehicle studies and the engine cycle trade studies were held on 23 and 24 June 1971 at SAMSO and RKD in Los Angeles, California. This memo summarizes the presentations made at those reviews.

Propulsion oriented reviews of the MDAC-W and NAR/SD vehicle studies and the propulsion contractor engine cycle trade studies were held on 23 and 24 June 1971 at SAMSO and RKD in Los Angeles California. This memo summarizes the presentations made at those reviews.

2.0 DISCUSSION

Table 1 presents the agenda of the meetings and Table 2 summarizes the desired engine operating characteristics that were to have been studied. Each of the propulsion contractors provided parametric data for several different bell nozzle engine cycles and derived preliminary design summaries for

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*"Main Propulsion Selections; Pre-Phase A NASA Space Tug Studies," Case 237, C. Bendersky, May 18, 1971.

8,000, 15,000, 25,000 and 50,000 lb thrust engine systems. RKD, in addition to these, performed the same tasks for engine cycles having aerospike nozzles. RPL then compiled and condensed the parametric data* and provided them to the SAMSO vehicle contractors who in turn performed propulsion optimization studies.

The studies are continuing and each propulsion contractor is now preparing a detailed point design at the 25,000 lb thrust level for his favorite bell nozzle engine cycle. RKD will prepare an additional 25,000 lb point design for an aerospike nozzle engine system.

2.1 Engine System Studies

Figure 1 lists trade-off parameters specified by RPL for use in comparing candidate engine cycles.

The bell nozzle engine cycles can be divided into two basic groups: open cycles and topping cycles.

In open cycles, turbine pressure ratio is high and low pressure exhaust gases are ducted overboard through the low pressure area of the supersonic portion of the main nozzle or through a separate low pressure nozzle. Open cycles include gas-generator, coolant bleed and chamber tap-off turbine gas arrangements.

In topping cycles, turbine pressure ratio is low and high pressure exhaust gases are ducted directly into the main combustion chamber and thereupon become undistinguishable from the main combustion products. Topping cycles include the staged-combustion and expander turbine gas arrangements.

Some combinations of open and topping cycles were also considered by the propulsion contractors.

The candidate cycles chosen by ALRC for study are shown schematically in Figures 2 and 3. Figure 4 summarizes the ratings. The staged combustion cycle was found to be the best performing across the 8,000-to-50,000 lb thrust range. Where available space is limited, higher thrust engines benefit more than lower thrust engines from use of a retractable nozzle.

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*"AFRPL TM-71-18 Parametric Engine Data for Orbit-to-Orbit Shuttle," (U), L. E. Tepe, June 1971.

The results of RKD's studies of cycles for bell nozzle engines were for all practical purposes the same as those of ALRC.

P&W chose not to consider a conventional staged combustion cycle but included a hybrid version called an augmented expander cycle. This cycle (Figure 5) uses chamber heated H_2 (like the expander RL-10) to provide most of the energy requirements. However before entering the turbine the hot H_2 is split and a smaller portion is burned with O_2 and then remixed with the main H_2 stream. This higher (augmented) energy gas allows the engine to operate at a higher chamber pressure than possible in a conventional expander cycle and requires a smaller precombustor than a conventional staged combustion cycle. As shown in Figure 6,* the augmented expander cycle engines performed best of those studied by P&W.

The aerospike engine cycles considered by RKD are shown in Figure 7. To operate efficiently an aerospike nozzle requires that a small part of the total propellant be ducted into the nozzle base area. In an open cycle the lower pressure turbine exhaust gases are used for this purpose. In a topping cycle the base gases are split off from the main flow before entering the combustion chamber. The RKD studies showed the expander cycle to be the best performing of the aerospike nozzle engines studied.

Because heat transfer characteristics of an aerospike engine necessitate operation at a lower chamber pressure than bell nozzle engines, the aerospike system did not compare favorably with the bell nozzle engines. In order to alleviate the aerospike heat transfer problem, RKD introduced a cooling concept called "double-panel chamberwall cooling" which uses both H_2 and O_2 regeneratively as shown in the schematic of Figure 8. The copper alloy (NARLOY) chamber liner has machined H_2 passages and NARLOY tubes for O_2 flow brazed into the H_2 cooling slots. The O_2 takes up approximately 25 percent of the heat flux previously carried away by the hydrogen. At 25,000 lb thrust the reduction of hydrogen coolant pressure drop allows the engine to operate at 1,000 psia and an area ratio of 200:1 compared to 750 psia and an $\varepsilon = 150$ for the conventional aerospike and specific impulse is increased 9 seconds. (It is noted that the double paneled aerospike is

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*Figures 4 and 6 show a fictitious Δ payload which would result if gravity losses and structural weights did not change. The optimum thrust level is determined by incorporating those additional factors.

conceptual and requires experimental verification.) Figure 9 is a summary of the aerospike expander cycle performance estimates for both single and double panel cooling at 8,000, 15,000, 25,000 lb and 50,000 lb thrust.

2.2 Vehicle Studies

Both NAR & MDAC-W conducted propulsion trades of 79,500 lb (max) gross weight single stages having capabilities of delivering 10,000 lb to or returning 3500 lb from synchronous orbit. Based on the RPL compiled propulsion data of Reference 1 both contractors concluded that:

(1) Staged combustion engines with boost pumps would be markedly superior to single panel aerospikes.

(2) Double paneled aerospikes approach the performance of staged combustion engines but have higher risk and would be more costly to develop.

(3) The bell nozzle engine total thrust would be optimum at approximately 20,000 lb. Either a single 20,000 lb thrust engine or two 10,000 lb thrust engines would be satisfactory.

(4) Dual engine aerospikes would not be desirable.

C. Bendersky

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Attachments

23 June at Rocketdyne

AFRPL Program Overview

Rocketdyne Summary

Tasks I, II, III

View Hardware

Aerospike Studies

Alternate Engine Studies

Engine Thermal Fatigue Program Presentation

24 June at SAMSO

SAMSO Upper Stage Studies Overview (Gov't personnel only)

North American Rockwell Space Division

McDonnell-Douglas - OOS Engine Design Studies

Pratt & Whitney

Aerojet

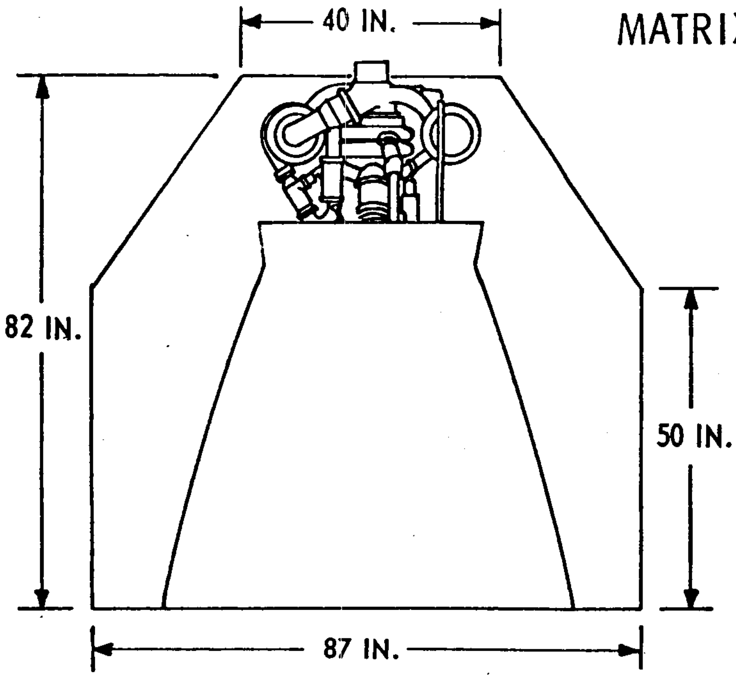
Government Caucus

TABLE 1. OOS PROGRAM REVIEW AGENDA

TABLE 2

8,000- TO 50,000-POUND THRUST ENGINE OPERATING CHARACTERISTICS

Propellants	Liquid Oxygen/Liquid Hydrogen
Maximum Vacuum Thrust, pounds	8,000 to 50,000
Number of Vacuum Starts	60
Lifetime (Expendable Mode), thermal cycles	6
Lifetime (Reusable Mode), thermal cycles	300
Lifetime (Reusable Mode), hours	10
Minimum Natural Frequency of Gimbal System, Hertz	10
Fuel Pump NPSH, feet of hydrogen	60
Oxidizer Pump NPSH, feet of oxygen	16
Maximum Single Run Duration, seconds	1000
Maximum Storage Time in Orbit (Dry), weeks	52
Maximum Time Between Firings (Coast Time), days	14
Minimum Time Between Firings (Coast Time), minutes	10
Maintenance-Free Engine Run Time, hours	2
Maintenance-Free Engine Firing Cycles	60



MATRIX OF ENGINE DESIGN CONSTRAINTS

- STOWED ENGINE ENVELOPE (LENGTH & DIA)
- LOW CYCLE FATIGUE LIFE $N_f = 300$
- ENGINE CYCLE POWER BALANCE LIMIT
- OPT PAYLOAD CAPABILITY

ENGINE PAYLOAD TRADE-OFF PARAMETERS:

LUNAR LANDER MISSION

- $\frac{\Delta PL}{\Delta I_s}$ = 114 LBS/SEC
- $\frac{\Delta PL}{\Delta W_{BURNOUT}}$ = -1 LBS/LBS

ORBIT-TO-ORBIT MISSION

- $\frac{\Delta PL}{\Delta I_s}$ = 157 LBS/SEC
- $\frac{\Delta PL}{\Delta W_{BURNOUT}}$ = -3.68 LBS/LBS

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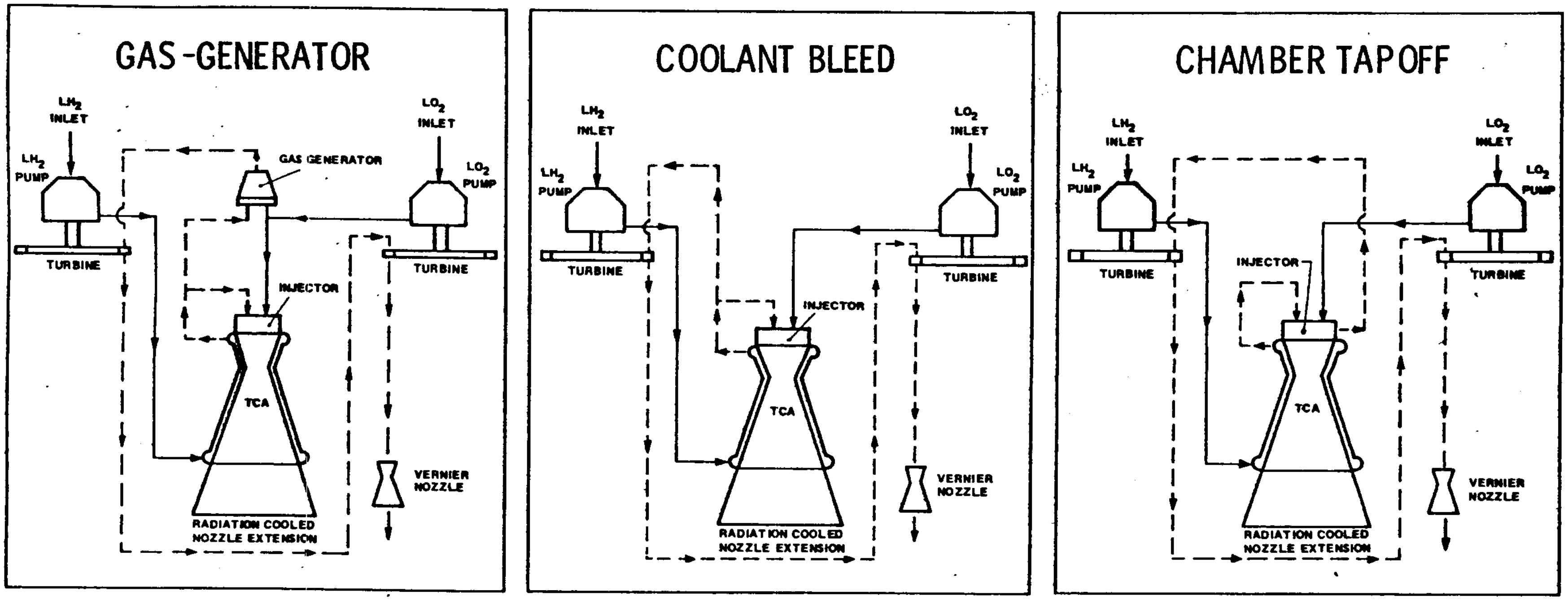
FIGURE 1. ENGINE DESIGN RESTRAINTS AND TRADEOFF PARAMETERS



- ENGINE PERFORMANCE DEGRADED BY TURBINE BLEED LOSSES
- THRUST CHAMBER PRESSURE LIMITED BY THRUST CHAMBER LIFE REQUIREMENT
- OPTIMUM CHAMBER PRESSURE DEPENDANT ON AVAILABLE ENGINE ENVELOPE

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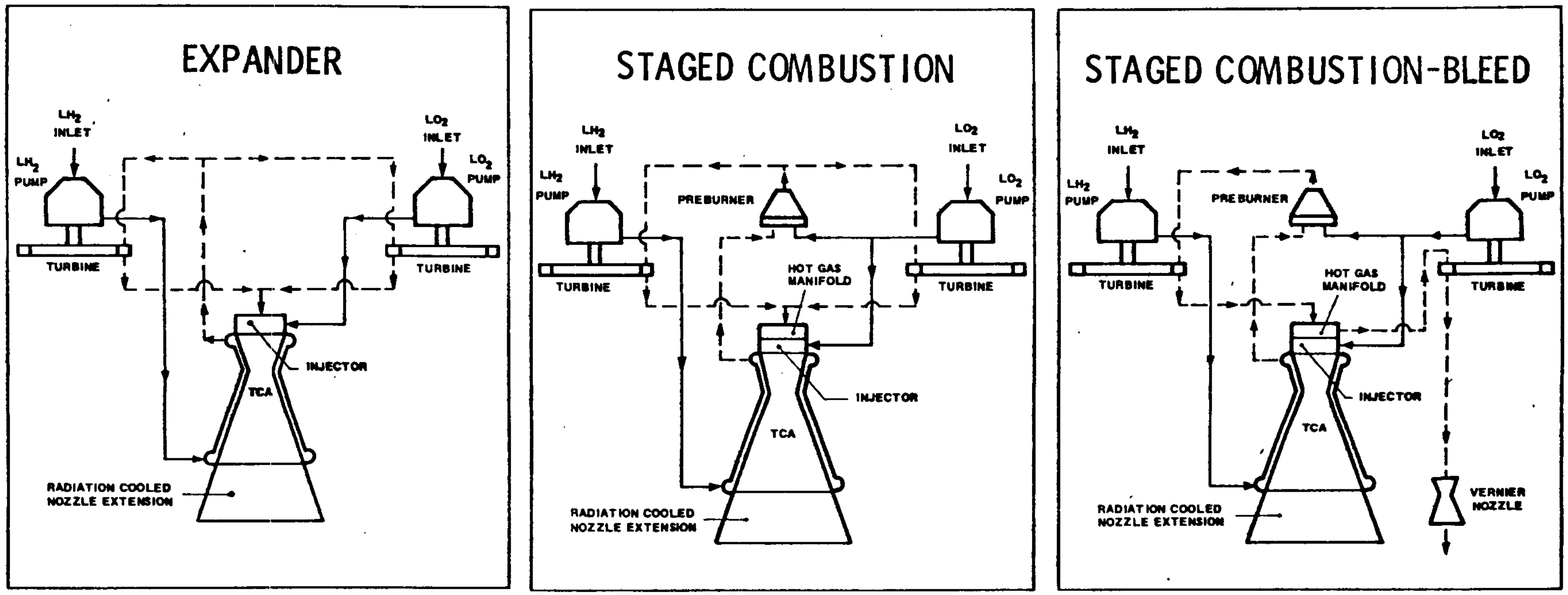
FIGURE 2. ALRC CANDIDATE BELL NOZZLE OPEN CYCLE SCHEMATICS



- ENGINE PERFORMANCE APPROXIMATES THRUST CHAMBER PERFORMANCE
- CHAMBER PRESSURE LIMITED BY FEED SYSTEM POWER BALANCE
- CHAMBER PRESSURE LIMITED THRUST CHAMBER LIFE REQUIREMENT

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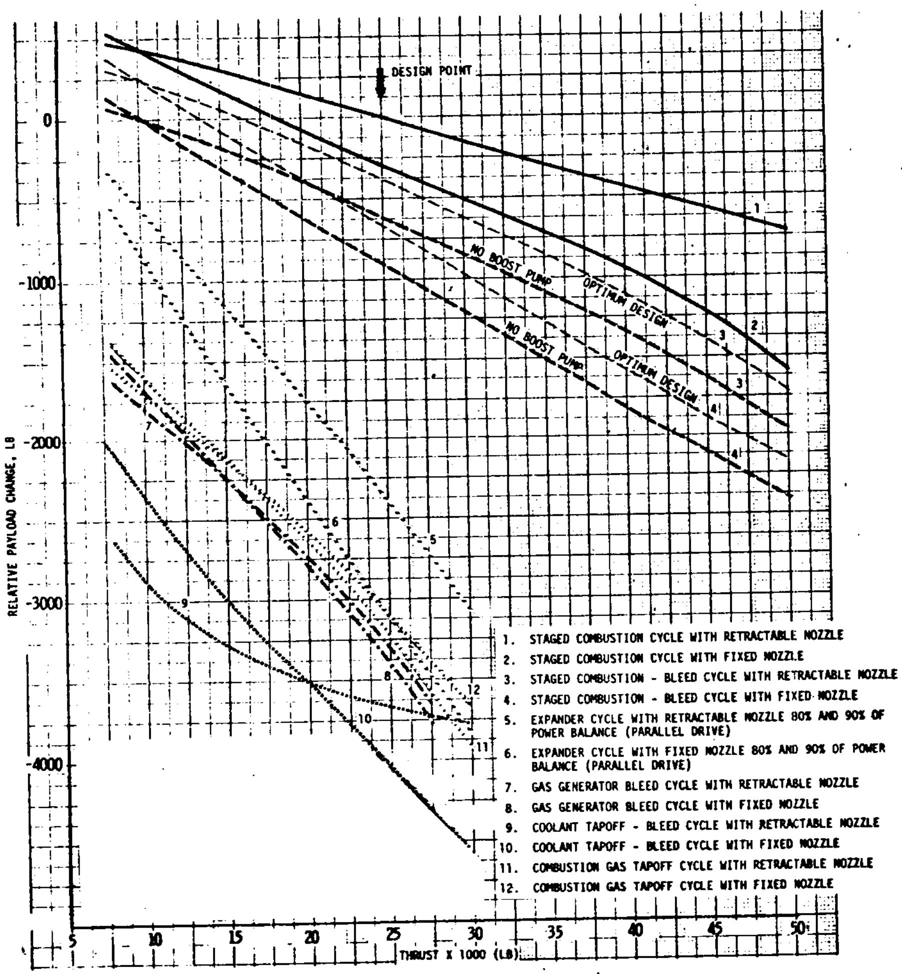
FIGURE 3. ALRC CANDIDATE BELL NOZZLE TOPPING & COMBINATION CYCLE SCHEMATICS

- ENGINE PAYLOAD COMPARISON



- PAYLOAD COMPUTED FOR EQUAL ENVELOPE FOR ALL THRUST LEVELS
- HIGH CHAMBER PRESSURE CYCLES HAVE HIGHEST PAYLOAD CAPABILITY 8K TO 50K
- HIGH PRESSURE CYCLES HAVE SMALL PL GAIN DUE TO RETRACTABLE NOZZLE
- LOW PRESSURE CYCLES BENEFIT GREATLY BY RETRACTABLE NOZZLE
- CYCLE PAYLOAD DIFFERENCE DECREASES WITH THRUST LEVEL (FIXED ENVELOPE)

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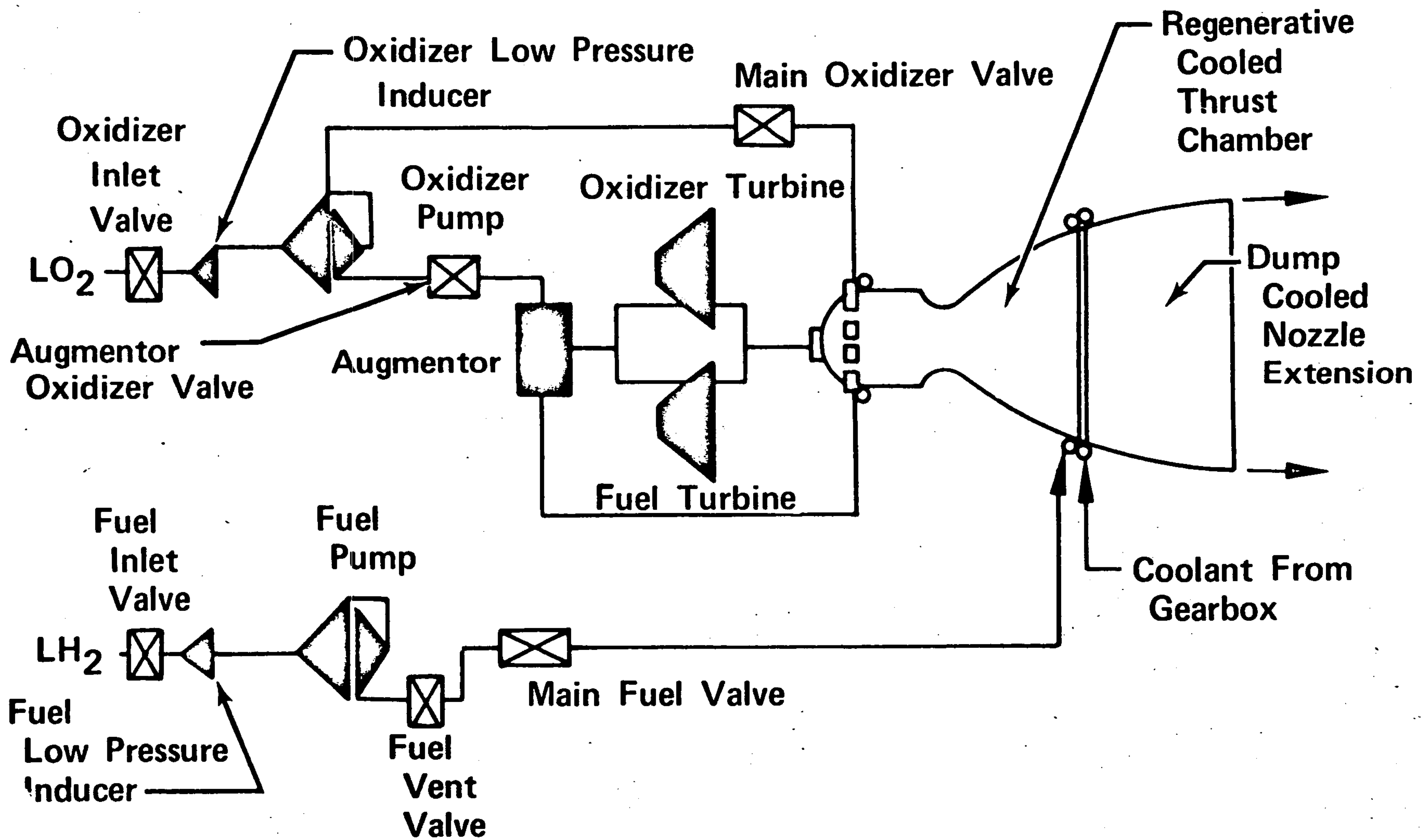
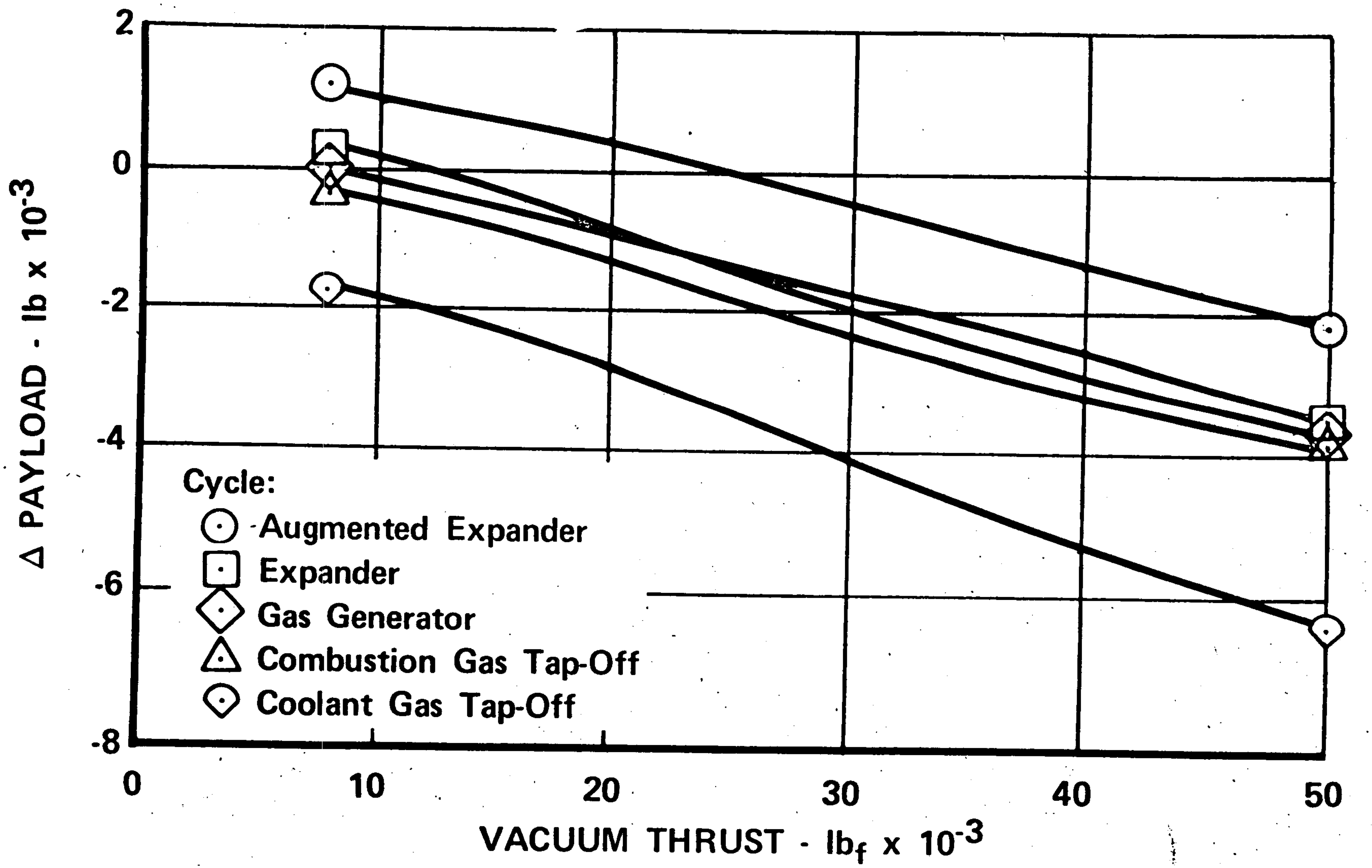
FIGURE 4. ALRC BELL NOZZLE ENGINE CYCLE TRADE RESULTS



Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

FIGURE 5. PRATT & WHITNEY BELL NOZZLE AUGMENTED EXPANDER CYCLE FLOW SCHEMATIC (TYPICAL)

FD 51506A
711506



Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION
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FIGURE 6. P&W BELL NOZZLE ENGINE CYCLE TRADE RESULTS

FD 51918
711506

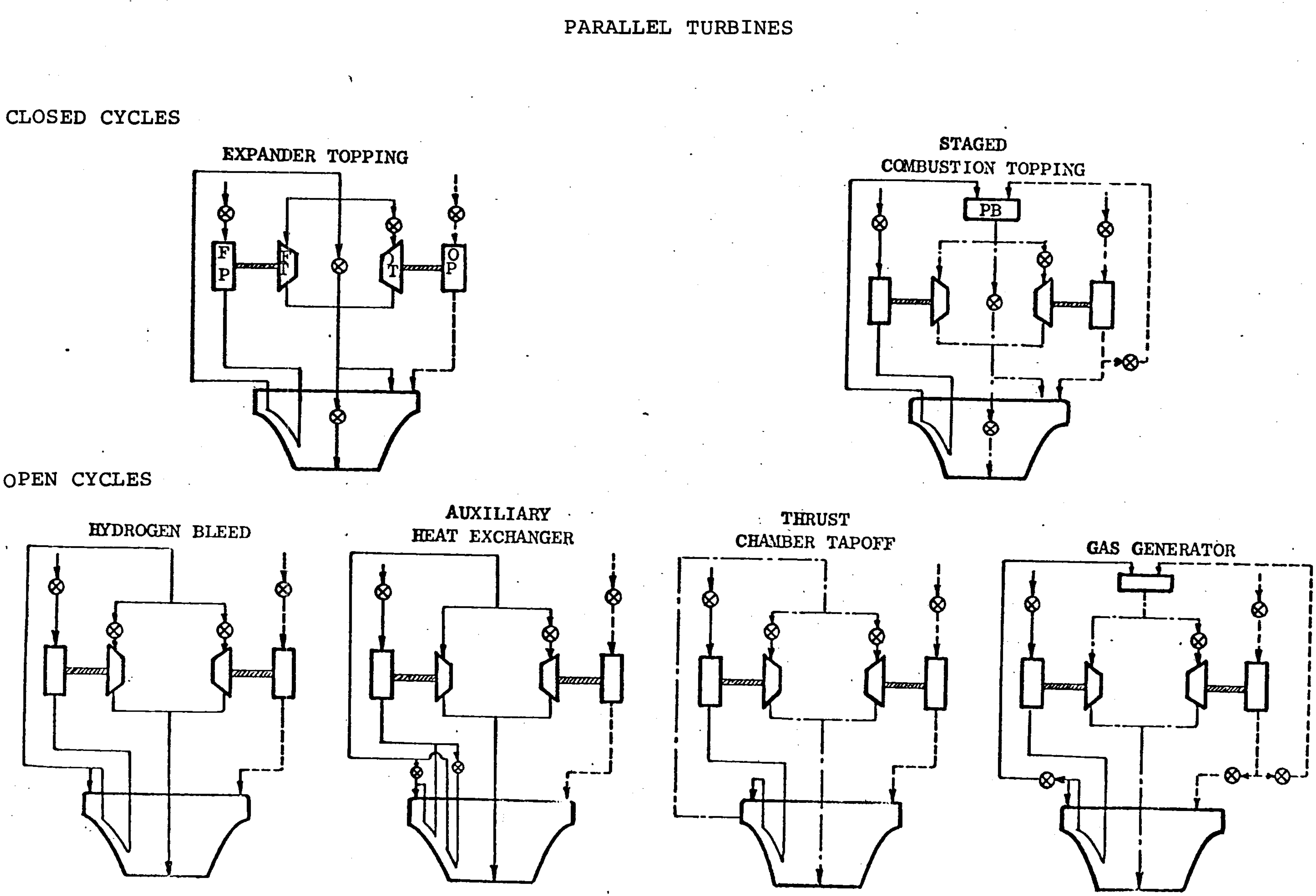
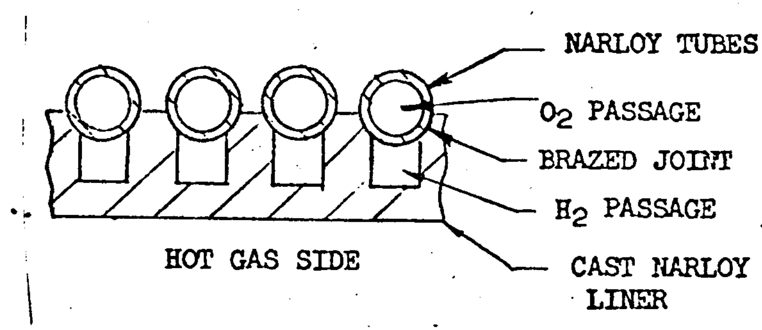


FIGURE 7. RKD AEROSPIKE CANDIDATE ENGINE CYCLE SCHEMATICS



- REGENERATIVELY COOLED BY BOTH H_2 AND O_2
- INCREASE PROPELLANT COOLING CAPACITY BY 25% AND MAXIMIZE EFFECTIVENESS
- INCREASE CHAMBER COOLING DESIGN LIMITS TO P_c = 1000 PSIA AND ϵ = 200 FROM 750 PSIA & ε = 150 FOR 25K LBF

FIGURE 8. RKD DOUBLE PANEL AEROSPIKE CHAMBER WALL COOLING CONCEPT

M.R. = 5.5:1

SINGLE PANEL COOLING CIRCUIT				
DESIGN THRUST LEVEL	8,000 lb.	15,000 lb.	25,000 lb.	50,000 lb.
T/P Cycle	Expander Topping	Expander Topping	Expander Topping	Expander Topping
Pc, psia	550	650	750	1000
ϵ	62	102	150	220
I_s, sec	449	456.6	462.1	467.3
Weight, lb.	102	197	345	737
Length, in.	11	16	22.5	32.5
Diameter, in.	32	46	62	92
DOUBLE PANEL COOLING CIRCUIT				
T/P Cycle	Expander Topping	Expander Topping	Expander Topping	Expander Topping
Pc, psia	500	800	1000	1225
ϵ	100	152	200	305
I_s, sec	452.0	466.6	471.1	473.4
Weight, lb.	118	219	375	822
Length, in.	14	17.5	23	31.5
Diameter, in.	40	48	64	98

FIGURE 9. RKD AEROSPIKE ENGINE PERFORMANCE SUMMARY

Subject: AF/OOS Propulsion Reviews, Los Angeles, California, June 23-24, 1971 - Case 237

From: C. Bendersky

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